ASE Electrified Propulsion Vehicles (xEV) High-Voltage Electrical Safety Standards

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Table of Contents

- OSHA Specific Duty Clauses
- OSHA Interpretation on Arc Flash Hazards
- SAE International Standards (Society of Automotive Engineers)

Notice and Disclaimers

Section A – Purpose and Definitions

<A0.1> Notice and Disclaimers

THE WORD **SHALL**, IN THIS STANDARD, IS USED TO IDENTIFY CONDITIONS THAT **ARE REQUIRED** AND **MUST** BE MET.

THE WORD **MAY**, IN THIS STANDARD, IS USED TO IDENTIFY CONDITIONS THAT **ARE RECOMMENDED** AND **MAY** BE MET.

***ASE Electrified Propulsion Vehicles (xEV) High-Voltage Electrical Safety Standards*, and its recommended practices are developed through a consensus standards development process approved and governed by ASE. This process brings together volunteers representing varied viewpoints and interests to achieve consensus on electrified propulsion vehicle safety issues. These *ASE Electrified Propulsion Vehicles (xEV) High-Voltage Electrical Safety Standards* are developed to serve as a guide, sharing existing industry standards, concepts, and practices followed by individuals working in the automotive, truck, and commercial electrical industry.**

ASE, its employees, its contractors, and consultants shall not be held liable for any personal injury, property damage, or other damages of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance on the *ASE Electrified Propulsion Vehicles (xEV) High-Voltage Electrical Safety Standards*. ASE, its employees, its contractors, and consultants also make no guarantee or warranty as to the accuracy or completeness of any information published herein.

<A0.2> Purpose

The purpose of the *ASE Electrified Propulsion Vehicles (xEV) High-Voltage Electrical Safety Standards* is to provide guidance, document, and establish electrical safety requirements, standards, procedures, and safe work practices relating to the development of an electrically safe working area for service professionals in North America working on or around electrified propulsion vehicles (xEVs)[1], alternating voltages >30 V AC rms and direct voltages >60 V DC[2], and conditions relative to the hazards arising from electrified propulsion vehicles and its components. The intent of this standard is to minimize exposure to these hazards and their associated impacts.

[1] Any electrified propulsion vehicle with a high voltage system, including, but not limited to, HEV, PHEV, PEV, BEV, FCEV, and EV – SAE J1715-1 SEP2022 Pg. 16 of 23.

[2] 30 V AC rms and 60 V DC per FMVSS 305 **High voltage source** means any electric component which is contained in the electric power train or conductively connected to the electric power train and has a **working voltage** greater than 30 V AC or 60 V DC. **Working Voltage** means the *highest root mean square voltage of the voltage source*, which may occur across its terminals or between its terminals and any conductive parts in open circuit conditions or under normal operating conditions.

Vehicles with high-voltage systems in some cases can be identified by:

- Vehicle badging and labels.
- Underhood high-voltage warning labels and cables.
- Batteries on roof or along frame rails (on trucks and busses).
- A charging port (on some, but not all, vehicles).

Electrified propulsion vehicles (xEVs) have high-voltage DC and AC systems; both are extremely dangerous and can cause personal injury, severe burns, electric shock, and even fatal injury. Alternating voltages >30 volts rms and direct voltages >60 volts are dangerous. Working on or near high voltage energized electrical equipment or systems presents electrical hazards, such as shock and arc flash and blast. These high voltages are dangerous if proper safety precautions are **NOT** followed.

Potentially dangerous electrical currents can be produced or carried by any of these distinct types of high-voltage components:

1. High-voltage battery pack.
2. Battery Management System (BMS).
3. High-voltage battery charging equipment.
4. High-voltage cables, orange in color, connecting components.
5. Inverter power electronics.
6. Capacitors inside the vehicle's inverter-rectifier assembly.
7. DC/DC converter.
8. Modules/electronic control unit(s).
9. Electric motor(s), also known as motor-generator(s) – (Regenerative braking).
10. Air conditioning compressor.
11. High-voltage heater(s).

<A1> Working Individual Definitions

<A1.1> LEVEL ONE – Electrically Aware Person is designed for anyone who may encounter an EV in the workplace. This includes an individual who performs tasks in proximity of electrified propulsion vehicles in sales, service, repair, and/or related environments. The LEVEL ONE individual requires high-voltage electrical safety awareness to identify the hazards and reduce the associated risks when working on or near electrified propulsion vehicles (xEVs) and/or near high-voltage components of electrified propulsion vehicles.

Skills performed by this individual can be, but are not limited to:

- Operating (driving) an electrified propulsion vehicle.
- Performing maintenance and repairs not related to high-voltage systems or their components.
- Handling non- high-voltage components of electrified propulsion vehicles.
- Encountering electrified propulsion vehicles and/or high-voltage components of electrified propulsion vehicles while performing job-related tasks.

<A1.2> LEVEL TWO – High-Voltage Vehicle Technician is a service professional, technician, or specialist who has received high-voltage electrical training, has demonstrated skills and knowledge related to the construction, operation, and repair of electrically powered high-voltage vehicles, maintains an electrically safe working area, and uses required personal protective equipment (PPE). They have also received safety training to identify the hazards and reduce the associated risk.

Skills performed by this individual can be, but are not limited to:

- Evaluating and classifying the condition of the high-voltage battery and high-voltage electrical system.
- Isolating the voltage from the high-voltage systems and checking the isolation from the supply.
- Securing the high-voltage system against being activated.
- Re-starting the high-voltage system.
- Performing general work on de-energized high-voltage systems and components.

- Assessing risk of high-voltage vehicles that were involved in an accident.

<A1.3> LEVEL THREE – High-Voltage Vehicle and Battery Technician is a service professional who has attained **LEVEL TWO** AND has received specific high-voltage battery pack training, can perform "live work," and has demonstrated such skills and knowledge.

Skills performed by this individual can be, but are not limited to:

- Performing all LEVEL TWO work.
- Performing diagnostic and repair work inside the high-voltage battery.
- Separating individual battery modules.
- Assessing the risk of high-voltage batteries or components where live work is necessary.

NOTE: As of January 1, 2023, the complete details of LEVEL THREE are **NOT** defined in this document.

SECTION B – GENERAL REQUIREMENTS FOR ELECTRICAL SAFETY-RELATED WORK PRACTICES

<B1> Electrically Safe Work Condition

An *electrically safe work condition* is a state in which a high-voltage electrical conductor(s) or circuit part(s), excluding inside the high-voltage battery pack, has been disconnected or isolated from energized high-voltage parts, locked/tagged in accordance with OSHA regulation 1920.147 (Occupational Safety and Health Administration), tested to ensure the absence of voltage, and for which while performing service the technician is no longer required to wear personal protective equipment (PPE).

An *electrically safe work condition* is not a procedure; it is a state wherein all hazardous electrical conductors, or circuit parts, to which a technician might be exposed are maintained in a de-energized state for the purpose of temporarily eliminating electrical hazards for the period of time for which the state is maintained.

Although the high-voltage systems of most electrified propulsion vehicles (xEVs) normally do not need to be disabled when performing routine non- high-voltage related maintenance, high-voltage systems must be de-energized and verified safe before high-voltage cables or components that are high-voltage related are disconnected or removed.

NOTE: LEVEL THREE is "Live Work" by nature. Live work is not electrically safe.

<B2> Risks Associated with Electric Vehicle Repair Include:

- High voltage isolation.
- Risks after a collision, primarily those that involve high-voltage battery integrity.
- Fire safety in shops and for first responders.
- High-voltage work.
- The possibility of the vehicle turning on unexpectedly.

<B2.1> Electrocution and Shock Hazard Risks – Electrical shock is the most likely hazard.

For technicians working on or around electrified propulsion vehicles (xEVs), there is a real danger of electrocution from larger batteries with greater potential energy and from the possibility of the vehicle or system activating unintentionally while work is being performed. Electrocution as low as

30 volts can result in fatalities. Voltages greater than 30 volts AC rms and greater than 60 volts DC are dangerous.

An electric shock can severely burn or kill if the muscle contraction is strong enough to stop the heart. Electrical currents can cause muscles to lock up, resulting in an inability to release the grip from the current source. This is known as the "**let-go**" threshold current, typically occurring at 6 to 16 milliamps (mA) or 16 one-thousandth of an amp. This muscle contraction will, in many cases, cause the victim to remain firmly gripped to the source of electrocution, particularly when that source is a high-voltage battery.

Current Level[3]	Probable effect on the human body
1 mA	**Slight tingling sensation.** Still dangerous under certain conditions.
5 mA	**Slight shock felt; not painful but disturbing.** The average individual can let go. However, strong involuntary reactions to shocks in this range may lead to injuries.
6-16 mA	**Painful shock, begin to lose muscular control.** Fall danger. Referred to as the freezing current or "**let-go**" range.
17-99 mA	**Extreme pain, respiratory arrest, severe muscular contractions.** Individual cannot let go. Death is possible.
100-2000 mA	**Ventricular fibrillation (uneven, uncoordinated pumping of the heart).** Muscular contraction and nerve damage begins to occur. Death is likely.
Over 2000 mA	**Cardiac Arrest, internal organ damage, and severe burns.** Death is probable.

[3] Voltage level at ~120 V 60 Hz. Source: US OSHA, CDC, NIOSH

A low-voltage electric shock can cause clinical effects of different types and severities, including cardiac arrhythmias, internal burns and poisoning, or kidney damage. Anyone who has experienced an electric shock, regardless of whether it has caused a burn, should seek advice from a healthcare professional.

Three primary factors affect the severity of the shock a person receives when placed in series with an electrical circuit. If any one of these factors is eliminated, then the electric shock may not be as severe.

First, the intensity, type, and frequency of the current, alternating (AC) or direct current (DC) flowing through the body, because current--not voltage--causes electric shock. Severity of the shock increases with higher current flow.

Second, the path the current takes through the body, typically down one side or across the heart. Using only one hand to make a measurement reduces the chance of current passing through the heart. The current must follow a path through the body (hand-to-hand, etc.) for fibrillation to occur.

Third, the length of time the body is part of the circuit and the body's resistance to the current.

Electrified propulsion vehicle systems present the risk of shock and electrocution when current takes an unintended path through a human body. Current as low as 75 milliamps (mA) across the heart is lethal. The internal resistance of the average human body is 300 Ω to 1,000 Ω. Most of the body's resistance is in the skin (epidermis) which fortunately is an extremely poor conductor. The resistance of dry skin is usually between 1,000 Ω and 100,000 Ω but it decreases exponentially when wet, burnt, or blistered. This means that when a person is electrocuted, the body's resistance drops as the skin is burned.

To calculate the amount of current that would course through a person's body if exposed to 400 V, divide 400 V by 600 ohms (I = V/R), which totals 0.66 amps or 660 mA. That is more than 8 times the lethal limit of 75 mA.

According to data from NIOSH 98-131[4] (National Institute of Occupational Safety & Health), most industrial fatalities from electrocution occur at lower voltages.

Voltages	110 V to 120 V	220 V to 240 V	270 V to 277 V	440 V to 480 V	Other
Fatalities	25	15	12	16	6

[4] NIOSH 98-131 U.S. Industrial Low Voltage Fatalities <600 volts (2021)

The technician **SHALL** carefully review **ALL** applicable original equipment manufacturer (OEM) safety-related repair manual procedures, training, and precautions **BEFORE** performing service.

NOTE: The technician should consult a medical professional if they have or are wearing:

- An implanted defibrillator.
- A cardiac pacemaker.
- An internal analgesic medication pump.
- An insulin pump.
- Hearing aids.
- Other medical devices.

<B2.2> Arc Flash and Arc Blast

As with any electrical system, fire is always a potential hazard. One of the most common causes is electrical arc faults, which are high power discharges of electricity between two or more conductors. The heat caused by this discharge can cause the wire insulation to deteriorate and thus cause a spark or "arc" that causes a fire.

A particularly hazardous type of shorting fault, an arc fault, occurs when the insulation or air separation between high-voltage conductors is compromised. Under these conditions, a plasma arc or "arc flash" may form between the conductors, unleashing a potentially explosive release of thermal energy.

This release of thermal energy triggers a bomb-like blast, the "arc blast." The heat at each end of an arc reaches up to and beyond 35,000° F (19,500° C). Metal from the vaporized conductors is rapidly expelled at >740 mph, emitting intense heat, molten metal, shrapnel, blinding light, toxic smoke, and a thermo-acoustic shock wave strong enough to cause contact with other dangerous equipment.

Electrified propulsion vehicle (xEV) systems are subject to both series arc faults caused by a disruption in continuity of a conductor or parallel arc faults caused by unintended current between two conductors, often due to a ground fault.

NOTE: Arc flash is a recognized hazard of batteries used with electrified propulsion vehicles, especially when damaged or defective. The US DOE (Department of Energy) reports battery fires as a major potential hazard of electrified propulsion vehicles. Flammable and toxic solvents are used in some lithium-ion batteries as well.

<B3> Equipotential Bonding Line

A voltage potential could exist between high-voltage components and the housing due to internal defects or moisture ingress. To minimize the risk of electric shock, arc flash, or arc blast, electrified propulsion vehicle components are connected through an *equipotential bonding line* to the vehicle chassis ground which proactively detects different potential voltages between components and will initiate pre-emptive isolation, preventing potential failures, if faults are detected.

<B4> Loss-of-Isolation Circuit

Electrified propulsion vehicles utilize a floating (isolated) ground which is NOT connected to the vehicle chassis ground. This is a built-in safety mechanism designed to store a diagnostic trouble code (DTC) after two consecutive trips with the same failure. For safety reasons, the vehicle is still driveable, however, some vehicles will not turn on once the vehicle power is shut off after the diagnostic trouble code is triggered.

<B5> Aiding Persons Subjected to High Voltage

DO NOT directly touch any person being subjected to a high-voltage shock.

If possible, follow these 3 steps:

1. ***Call*** **911** / emergency services.
2. ***Disconnect*** the source of high voltage:
    - Turn off the vehicle / switch off the ignition.
    - Turn off the high-voltage electrical supply at the source.
        - If the source is line voltage, it should be turned off at a service disconnect.
        - If the source is an electrified vehicle, the high-voltage system should be de-energized. Disconnect the high-voltage system through the manual service disconnect (MSD)[5]. Many newer, higher current systems use a low-voltage service disconnect lever to remove power from the contactor control circuits.

          [5] Manual service disconnect (MSD) is a SAE J1715 (Society of Automotive Engineers) standardized term to represent the orange removable connector that some electrified propulsion vehicles (xEVs) use.
        - If the source is the high-voltage battery, a disconnect may not be available.
3. ***Separate*** the person affected, or the electrical conductor, from the voltage supply using a non-conducting object such as:
    - an assistant wearing the proper high-voltage gloves and appropriate personal protective equipment (PPE).
    - an insulated retrieval hook (hot stick).

Note: A body tackle impact may be used if the insulated retrieval hook is not available, but **DO NOT** grab the person as you will become part of the circuit.

<B6> Personal Protective Equipment (PPE)

This standard refers to *general* guidelines and procedures for LEVEL TWO and LEVEL THREE technicians.

Some electrified propulsion vehicle (xEV) manufacturers may limit the required use of personal protective equipment (PPE) by a technician, instead relying on the integration of safety systems in the vehicle to ensure that high-voltage components are de-energized by using a scan tool or electronic means.

The technician **SHALL** refer to the employer's or original equipment manufacturer's (OEM) specific guidelines, procedures, and training when selecting the appropriate and recommended personal protective equipment.

All technicians **SHALL** remove **ALL** conductive items from their person (watches, rings, chains, body piercings, metal hair accessories, etc.) prior to working on any electrified propulsion vehicle (xEV).

Because the energy of an arc flash converts primarily to heat and light energy, the technician must be protected from burns. Heat energy, measured in calories, is used to assess the effectiveness of personal protective equipment (PPE). Personal protective equipment is designed and engineered to limit burns to a second-degree level which is curable and characterized by blisters. The onset of second-degree burns may occur at 1.2 calories per centimeter squared per second ($1.2/cm^2/s$) on the "Stoll" curve, the relationship between heat energy transfer and time. One calorie is equal to holding the tip of one's finger over a flame for one second.

NOTE: If an article of clothing is labeled as flame-resistant and not arc-resistant (AR rated), it *does not mean* that it is flame proof.

Technicians working on or near the high-voltage battery of an electrified propulsion vehicle (xEV) or energized high-voltage components of an electrified propulsion vehicle, **SHALL** wear approved arc-flash flame-resistant personal protection equipment (AR/FR PPE) clothing, made of natural fibers such as cotton, not polyester. It is possible that a uniform manufacturer may incorporate a polyester blend in clothing which could prove dangerous if involved in an arcing incident.

NOTE: High-voltage personal protective equipment (PPE) stamped with certification dates **SHALL NOT** be used if they have ***expired*** certifications.

<B6.1> Electrical Insulating Gloves – Class 0 Electrical Safety Gloves (Recommended)

Electrically insulated rubber gloves (sometimes called lineman's gloves) **SHALL** be worn on both hands when working near **ALL** electrified propulsion vehicle (xEV) high-voltage components, when energized, and **always** when working with the vehicle's high-voltage batteries.

Insulated gloves offer personal protection against electrical shocks when working on or near live conductors and **SHALL** comply with IEC 60903 (International Electrotechnical Commission) and ASTM D120 (American Society for Testing and Materials) standards.

Fully insulated gloves **SHALL** be stamped for **MAX USE VOLT 1000V AC**, have a red-colored label with a voltage range and have an expiration date indicating a laboratory test within the last 6 to 18 months per OSHA 1910.137 (Occupational Safety and Health Administration).

The length is important because 12-inch rubber gloves have a rolled cuff, so the lower arm will be protected when testing using a meter.

Always store the gloves flat, in a protective bag with the open cuff down, and not rolled or folded.

NOTE: Ordinary latex, nitrile, and neoprene gloves **SHALL NOT** be used as a substitute as they are not thick enough and do not provide sufficient protection from the shock hazard.

To make the testing easier, one person at the shop should oversee all rubber glove testing. Employers should stock two pairs of gloves, alternating them when one pair is received and ship the other pair back for testing. This will help to ensure the test has been done within the defined timeframe.

According to OSHA 1910.137[6], Table I-5, rubber insulating gloves must be tested before first issue and every six months thereafter and, upon indication that insulating value is suspect, after repair, and after use without protectors. For insulating gloves, the standard clarifies that if the gloves have been electrically tested but not issued for service, they may not be placed into service unless they have been electrically tested within the previous 12 months. Under regular use, the best practice is to test gloves as frequently as monthly.

[6] Based on ASTM D120 (American Society of Testing and Materials), Standard Specification for Rubber Insulating Gloves.

NOTE: Refer to glove manufacturer's information for use and re-certification requirements.

Before each use, and whenever there is a reason to believe they may have been damaged, electrical insulating gloves **SHALL** be visually inspected for cuts, splits, cracks, ruptures, tears, pinholes, or damage and surface defects, and inflated to detect air leaks using a pneumatic glove pump or air-tested using a rollup method, prior to and immediately after each use. If each glove holds air, the user is safe to continue using the glove.

The technician **SHALL NOT** use shop compressed air to test gloves and **SHALL NOT** wear gloves that are damaged.

<B6.2> Approved Leather Over-Gloves

The technician **SHALL** wear proper mechanically protective over-gloves meeting ASTM F696 and/or ASTM F3258 (American Society for Testing and Materials) to protect the rubber insulating gloves against mechanical hazards, prevent damage, and protect against electrical arcing.

Grease or metal shavings are conductive and could result in a hazard or fire when exposed to high voltage. Over-gloves should be inspected for damage and contamination prior to and after each day's use, and **NOT** be used if contaminated.

<B6.3> Insulating Sleeves

Insulating sleeves meeting ASTM D1051 (American Society for Testing and Materials) **MAY** be used if work practices cannot prevent touching energized parts using gloves alone; refer to OSHA 1910.137 (Occupational Safety and Health Administration) for additional information.

<B6.4> Protective Footwear

Technicians **MAY** wear shoes or boots that are rated per OSHA 1920.136 (Occupational Safety and Health Administration), ASTM 2413-11[7] (American Society of Testing and Materials) for electrical hazard when working in proximity to an **energized** electrified propulsion vehicle (xEV). They *must* be kept dry to insulate the wearer from 18 kV at 60 Hz AC for 1 minute or provide continuous protection for up to 750 volts and be clean and free of oil or conductive debris such as metal shavings.

[7] -11 denotes 2011 or newer rating

<B6.5> Insulated Retrieval Hook

An insulated retrieval hook, also known as a "Hot Stick" or "Rescue Hook" provides electrical insulation protection using a closed-cell, non-conductive, foam-filled tubular fiberglass pole, safeguarding individuals assisting others that may become disabled from electrical shock. When responding to emergency situations in or around an electrified propulsion vehicle (xEV), while helping to withdraw injured workers out of a hazardous area, an insulated retrieval hook may be used.

The shop **MAY** have an Insulated Retrieval Hook available for use in an emergency, **OR** individuals **SHALL** be professionally trained on how to separate a person from an active circuit in case of electrocution (using equipment such as an electrically insulated gloved assistant or a body tackle impact).

<B6.6> Insulating Rubber Apron

The technician **MAY** wear an approved electrical safety apron when appropriate, certified to ASTM F2677 (American Society for Testing and Materials) standards.

<B6.7> Safety Glasses or Goggles

Technicians working on or around electrified propulsion vehicles (xEVs) **SHALL** wear eye protection or safety glasses when exposed to electrical hazards or electrical arc, in compliance with OSHA 1910.133(a) (Occupational Safety and Health Administration): "The employer shall ensure that each affected employee uses appropriate eye or face protection when exposed to eye or face hazards from flying particles, molten metal, liquid chemicals, acid or caustic liquids, chemical gases or vapors, or potentially injurious light radiation." – OSHA 1910.133(a)(1), and "The employer shall ensure that each affected employee uses eye protection that provides side protection when there is a hazard from flying objects. Detachable side protectors (e.g., clip-on, or slide-on side shields) meeting the pertinent requirements of this section are acceptable." – OSHA 1910.133(a)(2).

Polycarbonate lenses are stronger than glass and plastic lenses and can absorb a greater impact. Look for an ANSI Z87+ (American National Standards Institute) marking. OSHA 1910.133 requires ANSI Z87.1-2010 or newer standards be met. If these are worn throughout the day, look for anti-fog, anti-scratch, anti-static, and 99.9% UV protection coatings.

<B6.8> Hearing Protection

The technician **MAY** use appropriate hearing protection (ear canal inserts) when servicing energized components and high-voltage battery packs.

<B6.9> Face Shields – Arc Class 2 (Recommended)

The face shield provides forehead protection, has a full 180° field of vision, and is rated for arc thermal protection values. Shields are used for thermal isolation and are flame-resistant.

The face shield must have an arc thermal performance value (ATPV) rating of 9.9 calories/cm2 and is NFPA 70E arc Class 2 (National Fire Protection Association) and ANSI Z87 (American National Standards Institute) impact protection certified.

The technician **SHALL** wear a face shield to protect their eyes from any "flash over" or arc flash that can occur if electrical arcing is produced when working on energized components or electrified propulsion vehicle (xEV) batteries.

Face shields should be cleaned and stored properly immediately after use.

<B6.10> Rubber Insulating Matting – Class 0 mats (Recommended)

Rubber insulating matting, or switchboard matting, **MAY** be used when working on energized high-voltage components, high-voltage batteries located in the vehicle, and high-voltage batteries outside of the vehicle.

These mats are non-conductive and designed to insulate technicians, protecting them from deadly shocks generated through high-voltage contact.

Class 0 mats are flame retardant, oil/acid resistant, tested to 5 kV for up to 1000 V maximum working voltage, and proven to have a high dielectric strength. However, to provide a large margin of safety, the maximum recommended voltage exposure is much less. These mats are true electrical safety mats that meet ASTM D178-01 or D1048 (American Society for Testing and Materials) specifications and **SHALL** be certified to IEC61111 (International Electrotechnical Commission).

<B7> Insulated Hand Tools

The following requirements **SHALL** apply to insulated tools:

- Insulated tools **SHALL** be rated for the voltages on which they are used, both DC and AC.
- Insulated tools **SHALL** be designed and constructed for the environment to which they are exposed and for the intended way they are to be used. They are designed for use ONLY on high-voltage systems and should not be used in any other repair applications.
- Insulated tools and equipment **SHALL** be inspected prior to each use. The inspection **SHALL** look for damage that could limit the tool from performing its intended function or could increase the potential for an incident.

- Insulated tools **SHALL** be protected from damage to the insulating material.

When working on energized high-voltage components or high-voltage batteries of electrified propulsion vehicles (xEVs), the tools and handling equipment required by the vehicle manufacturer **SHALL** be insulated and meet the *Standard Specification for Insulated and Insulating Hand Tools*, ASTM F1505-10 (American Society for Testing and Materials), OSHA 1910.335(a)(2)(i)[8] (Occupational Safety and Health Administration) and IEC 61243-1[9] (International Electrotechnical Commission).

[8] When working near exposed energized conductors or circuit parts, each employee shall use insulated tools or handling equipment if the tools or handling equipment might make contact with such conductors or parts. If the insulating capability of insulated tools or handling equipment is subject to damage, the insulating material shall be protected.

[9] The use of this symbol is specified, for example in **IEC** 60900 (International Electrotechnical Commission) for hand tools for live working up to 1000 V AC and 1500 V DC, in IEC 60903 for gloves and mitts of insulating material and in IEC 61243-1 for voltage detectors of capacitive type. These publications require to have the number of the IEC standard immediately adjacent to the symbol. (2) This symbol should be used in the orientation shown.]; Published in: Edition 3, 2002 and Amendment 2, 2002;3C/762/FDIS; New edition, 1998;3C/358/FDIS;3C/331/CDV;3C/298/CD.

<B8> Physical Barriers, Signage, and Boundary Guarding

A defined combination of safety signs, cones, tape, tags, and a magnetic car topper identifying whether the vehicle is 1) energized or 2) non-energized **SHALL** be used to warn individuals about electrical hazards that might endanger them and to mark off electrified propulsion vehicle (xEV) service areas where necessary. Such signs and tags **SHALL** meet the requirements of applicable state, federal, or local codes and standards.

Barricades[10] **SHALL** be used along with signs and tags to prevent or limit access to work areas containing live activated components operating at **30 V AC rms or 60 V DC** or more and attendants shall be used when signs and barricades do not provide sufficient warning and protection from the electrical hazards.

Conductive barricades **SHALL NOT** be used where it might increase the likelihood of exposure to an electrical hazard.

[10] OSHA 1910.335(b)(2) (Occupational Safety and Health Administration) Barricades. Barricades shall be used in conjunction with safety signs where it is necessary to prevent or limit employee access to work areas, exposing employees to uninsulated energized conductors or circuit parts. Conductive barricades may not be used where they might cause an electrical contact hazard.

As required by the vehicle manufacturer, the technician **SHALL** maintain a defined safety zone around the work area and place warning signs when high-voltage system repairs are left unattended.

<B8.1> Shop Safety Alerting Techniques

Traffic in the area can pose a substantial hazard. This includes foot traffic, as well as vehicles and other types of shop equipment. Barriers, barricades, signs, and an attendant may be needed to prevent intrusion into the work zone.

The LEVEL TWO and/or LEVEL THREE technician(s) **SHALL** be responsible for safety and security when an electrified propulsion vehicle (xEV) enters the work area.

SECTION C – ESTABLISHING AN ELECTRICALLY SAFE WORK CONDITION

NOTE: LEVEL TWO and LEVEL THREE technicians **SHALL** be fully trained on the specific high-voltage system and read original equipment manufacturer's (OEM) high-voltage disable procedures (de-energizing) and follow all safety precautions before working on or near electrified propulsion vehicles (xEVs).

<C1> LEVEL ONE Knowledge and Skills

<C1.1> Maintain Proficiency in Electrical Safety (Refer to: *SECTION F – Test Instruments and Equipment for Electric Vehicle Applications in this document for detailed information*)

The person **MAY** be trained and tested for proficiency in:

- Emergency Response training including use of specialized response equipment.
- First-aid training including Cardiopulmonary Resuscitation (CPR).
- Electrified propulsion vehicle (xEV) Safety Training.

<C1.2> Safety Concepts on and around an Electric Vehicle

The person **SHALL** be trained and tested for proficiency in the following areas:

- Identify electrified propulsion vehicle (xEV) high-voltage components.
- Identify high-voltage circuits.
- Identify the various warning lights and labels on and around the vehicle.
- Understand the safety concerns associated with servicing electrified propulsion vehicles including:
    - Scheduled maintenance and conventional "low-voltage" services.
    - High-voltage services and repairs.
    - The shop's procedures and safety practices for working on high-voltage systems.

The LEVEL ONE person **SHALL NOT** touch a Manual Service Disconnect (MSD) or any of the high-voltage components.

<C2> LEVEL TWO Knowledge and Skills

A LEVEL TWO individual **SHALL** "demonstrate" to their employer the skills of a LEVEL ONE person **AND** be able to demonstrate their knowledge and skills related to the following:

<C2.1> Maintenance and Applications of All Personal Protection Equipment (PPE)

The LEVEL TWO person **SHALL** be re-qualified according to employment requirement(s).

<C2.2> Safety Training and Proficiency Certification for the Electric Vehicle Applications

The LEVEL TWO person **SHALL** be evaluated regarding skills and knowledge related to the electrified propulsion vehicle (xEV) systems that they are trained to work on:

- **SHALL** read, understand, and follow the safety procedures in the original equipment manufacturer's (OEM) repair manual and all applicable service bulletins for the vehicle.
- **SHALL** use high-voltage personal protective equipment (PPE) gloves, safety glasses, and other appropriate personal protective equipment, whenever servicing high-voltage systems as required.
- After disconnecting a manual service disconnect (MSD) or other high-voltage disabling method, **SHALL** wait the original equipment manufacturer prescribed time before touching any of the high-voltage connectors or terminals.
- **SHALL** be responsible for managing the safety of ANY electrified propulsion vehicle or high-voltage parts they are working on.

- As required by the vehicle manufacturer, **SHALL** maintain a defined “safety zone” around the work area and place warning signs when high-voltage system repairs are left unattended.
- **SHALL** follow ALL CAUTION labels attached to high-voltage parts.

<C3> LEVEL THREE Knowledge and Skills

A LEVEL THREE individual **SHALL** “demonstrate” to their employer the skills of a LEVEL TWO person **AND** be able to demonstrate their knowledge and skills of working with high-voltage batteries and ALL high-voltage sub-components and be able to perform diagnostics on potentially energized components and/or circuits.

NOTE: As of January 1, 2023, the complete details of LEVEL THREE are **NOT** defined in this document.

<C4> Employer (Shop) Responsibilities

Shops **MAY** have, provide, and maintain:

- A safe working environment for electrified propulsion vehicles (xEVs) with a sufficient work area.
    - Service bay layout and workflow.
    - Adequate lighting to see the work being performed.
    - Access restriction and guarding.
    - Limits on foot traffic of other technicians and individuals.
    - Availability of Electric Vehicle Supply Equipment (EVSE) and suitable power supply.
    - Equipment and workbench(s) with non-conductive surfaces.
    - Rubber mats and a non-conductive area.
    - Secured storage area for high-voltage components, operational and/or damaged.
    - Storage of special equipment and personal protective equipment (PPE).
    - Lifting equipment for movement of high-voltage battery and heavy components.
    - Dual-post lift outfitted for battery fixture jack.
- Personal protective equipment (PPE) for LEVEL TWO and LEVEL THREE person(s).
- An electrified propulsion vehicle (xEV) Service Safety Kit: (Refer to: *<B8> Physical Barriers, Signage and Boundary Guarding in this document for detailed information*)
    - Magnetic car topper.
    - Electrified propulsion vehicle service bay caution barricades.
    - Electrified propulsion vehicle service bay caution cones.
    - Barricade caution tape.
    - Appropriate fire extinguisher.
    - Class-0 electrical safety gloves and leather over-gloves.
    - Glove leak tester.
    - Protective shield head gear.
- Proper tools and service equipment.
- Training and re-training including demonstration of proper safety procedures.
- A log/records of training and documentation.
- A glove certification/in service log.

OSHA 1910.335 (Occupational Safety and Health Administration) regulations require technicians to "demonstrate" their skills to their employer. Thus, employers **SHALL** verify an individual's ability to safely use test equipment and work on electrified propulsion vehicles (xEVs) following the original equipment manufacturer's (OEM) recommendations.

<C4.1> Provide Emergency Response Training and Equipment in the Case of an Electrocution or Injury
The LEVEL ONE, LEVEL TWO, and LEVEL THREE person(s) **SHALL** be trained.

<C4.2> Provide First Aid Training and Skills Assessment Including CPR (Cardiopulmonary Resuscitation)
The LEVEL ONE, LEVEL TWO, and LEVEL THREE person(s) **MAY** be trained.

<C4.3> Provide Safety Training and Proficiency Certification for Electric Vehicle (EV) Applications
The LEVEL TWO and LEVEL THREE person(s) **SHALL** be trained.

<C4.4> Shops SHALL Align with Existing Safety Requirements and Regulations
NFPA 70E (National Fire Protection Association), OSHA (Occupational Safety and Health Administration), and regional/local.

NOTE: In the event of a fire, follow the shop's Emergency Action Plan (EAP) Standard Operating Procedure (SOP) and only fight a controllable fire if the fire is small and is not spreading to other areas, and escaping the area is possible by backing up to the nearest exit. Make sure someone has called 911 and has notified the fire department that the vehicle involved is an electrified propulsion vehicle (xEV). If the high-voltage battery appears to be the source of the fire, everyone must leave the building and/or area immediately.

Section D – Safety-Related Work Practices

<D1> High-Voltage Lithium-ion (Li-ion) Batteries and Systems

Battery packs in electrified propulsion vehicles (xEVs) typically range in voltage from 100 V to 400 V DC but can be as high as 800 V DC (common in new battery electric vehicles), or greater as production increases. Larger trucks and buses can have voltage exceeding 1200 V DC.

<D1.1> Electrical Isolation and Handling Procedures of Battery (Modules, Bricks And/or Sections)

Lithium-ion (Li-ion) batteries are high energy per unit mass dense arrays that contain flammable electrolytes and toxic substances like nickel, cobalt, lithium, and manganese, and if damaged, incorrectly charged, or overheated, can lead to toxic release, explosions, and fires. Lithium-ion batteries are dry cell batteries that contain an electrolyte, which is considered potentially corrosive, toxic, and flammable.

Lithium-ion (Li-ion) Battery Characteristics:

- High power-to-weight ratio.
- High energy efficiency.
- Higher temperature performance.
- Low self-discharge.

The Battery Management System (BMS) monitors the battery state-of-health, temperature, and cell voltages. Electrified propulsion vehicles (xEVs) have integrated air--or liquid--cooling systems designed to keep the battery temperature low while the electrified propulsion vehicle is running or charging, preventing excessively high temperatures; some incorporate battery heating systems as well to keep the high-voltage battery within its optimum efficiency range of approximately 77° F to 95° F (25° C to 35° C). A crash or an overcharging event can cause electrified propulsion vehicle batteries to ignite.

Depending on the high-voltage components, the external packaging of the battery pack and electrical system components may be constructed with tough, Ingress Protection (IP)-rated casings ranging from IP65 to IP68, which provide dust and water protection. The battery and components must be inspected to ensure that there are no cracks in the housings or defective seals which may allow water and dust to penetrate.

When a battery no longer provides the desired range for use in a vehicle, it can have another decade of use for electrical storage, according to multiple reports. But sooner or later, most batteries will need to be dismantled and recycled — or disposed of as hazardous waste. Consumer Reports estimates the average high-voltage battery pack of an electrified propulsion vehicle has a lifespan of around 200,000 miles, which is nearly 17 years of use if driven 12,000 miles per year. A recent EPA (Environmental Protection Agency) report found that Lithium-ion batteries caused at least 65 fires at municipal waste facilities in 2021, though most were ignited by smaller batteries, like those made for cell phones and laptops.

<D1.2> Accident Risks

The vehicle has redundant systems that are designed to prevent shock and reduce fire hazard exposure to occupants and first responders. However, if the battery is compromised and internal components are punctured, crushed, or damaged, a safety risk could be created. The Lithium-ion (Li-ion) battery pack may contain *stranded energy* if there is stored energy in the battery or capacitors after an accident.

Stranded energy can release a dangerous level of high voltage, from 100 V DC to 800 V DC or greater. Sizzling or popping noises, leaking, dripping fluids, a chemical smell, smoke, or sparks from the battery area are indicators of a shorting condition. Emergency responders should be notified.

Thermal runaway is an event described by NFPA (National Fire Protection Association) as an uncontrollable self-heating of a battery cell that begins when the heat generated within the battery exceeds the amount of heat that can be safely dissipated to ambient surroundings. In an accident, an overheated damaged cell may generate toxic and flammable gases that could reach a level high enough to ignite.

Lithium-ion (Li-ion) batteries can be very difficult to extinguish once they are on fire; the main goal of emergency personnel is to cool the battery by flooding the battery compartment with water.

LEVEL ONE (as defined by task), LEVEL TWO and LEVEL THREE workers **MAY** review the *SAE (Society of Automotive Engineers) Surface Vehicle Recommended Practice J2950* standard: (https://www.sae.org/standards/content/j2950_202006), *SAE Hybrid and EV First and Second Responder Recommended Practice* J2990 201907: (https://www.sae.org/standards/content/j2990_201907/) and/or the *NTSB (National Transportation Safety Board) Lithium-Ion Safety for the First Responders*: (https://www.ntsb.gov/safety/safetystudies/Pages/HWY19SP002.aspx) document(s) that instruct how to deal with damaged batteries and emergency response procedures.

NOTE: If the battery has been damaged or punctured, the vehicle should be isolated *at least 50 feet away from other flammable or combustible materials*.

<D2> Procedures for Handling Batteries Weighing ~ 1000 to >3500 Pounds

Manual handling risks are associated with heavy battery pack replacement or disposal; technicians **SHALL** follow the original equipment manufacturer's (OEM) instructions for removal and installation.

An electrified propulsion vehicle (xEV) battery service **MAY** require:

- Lifting equipment to facilitate battery pack removal.
- Special equipment for the make and model of vehicle.

<D3> Wiring/Cabling – SAE (Society of Automotive Engineers) Standards for Nominal System Voltage up to 1000 V (AC rms or DC)

Insulation/Sheathing and Connector Identification

Color-coded high-voltage cables in electrified propulsion vehicles (xEVs) warn of their potential danger. These are ORANGE[11], insulation or wrapping.

[11] High-voltage cables are required to be orange per US FMVSS 305 S5.4.1.2 (Federal Motor Vehicle Safety Standards) high-voltage cables. Cables for high voltage sources over 30V AC rms or 60 V DC which are not located within electrical protection barriers shall be identified by having an outer covering with the color orange.

Color coding **SHALL** be verified with the original vehicle manufacturer (OEM) prior to work being performed.

Electrified propulsion vehicles (xEVs) utilize integrated electrical leakage detectors (loss of isolation) within the inverter or other high-voltage components, designed to detect defects in insulation or physical damage.

Technicians **SHALL NOT** pierce or cut into a high-voltage wire when testing for voltage. This may create a dangerous shorting condition, disable the system, and permanently damage the cable.

LEVEL TWO and/or LEVEL THREE trained technician(s) **SHALL** avoid contact with OR any attempt to remove or replace any high-voltage cables, wiring, and/or connectors, unless the high-voltage battery has been disconnected, isolated, verified safe and confirmed in a non-energized state, using the approved lockout de-energizing procedures when performing repairs external to the high-voltage battery.

The technician **SHALL** perform an insulation inspection and use testing practices and procedures utilizing an insulation testing tool prior to reconnecting the high-voltage battery.

<D4> High-Voltage Capacitors >400 V DC

The technician **SHALL** wait the prescribed amount of time as recommended by the original equipment manufacturer (OEM) after disconnecting the manual service disconnect (MSD) to verify discharge BEFORE touching ANY of the high-voltage connectors or terminals when performing repairs external to the high-voltage battery.

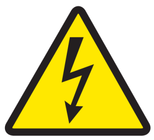
NOTE: Walking across the carpet, static builds: A human is like a capacitor of 100 picofarads, charged to a voltage of 4,000 to 35,000 volts, discharged in less than a microsecond.

<D5> Working On or Near Electric Vehicles

Labeling

The technician **SHALL** be familiar with and follow all original equipment manufacturer's (OEM) guidelines for identifying and following labeling on the vehicle and system being worked on. Warning labels are placed on the vehicle to indicate danger caused by electrical current.

- Special warning labels are found on the high-voltage battery.
- All high-voltage components and modular parts are labeled with an internationally recognized warning sign like:



- Labeled components **SHALL** not be opened or are to be opened **only** according to original equipment manufacturer's (OEM) instructions by a LEVEL TWO or LEVEL THREE person.
- The high-voltage system **SHALL** be secured against switching ON again through an approved Lockout/Tagout (LOTO) process.

SECTION E – DE-ENERGIZING

These procedures are generic; the technician **SHALL** refer to the original equipment manufacturer's (OEM) recommended repair and de-energizing procedures before proceeding.

<E1> De-energizing Procedure

1. De-energize the system.
2. Ensure the system cannot be reactivated.
3. Using a CAT III 600 V, CAT III 1000 V, or CAT IV 600 V digital multimeter (DMM), verify that no voltage is present at the contactors following the *<E4> Absence of Voltage Verification Process* described later.

<E2> Prior to Service or Repair:

Prior to working on or around high-voltage components[12], the LEVEL TWO person **SHALL** disable the high-voltage electrical system following the original equipment manufacturer's (OEM) recommended procedures for disconnecting (de-energizing) the high-voltage battery pack.

[12] Many vehicles have other procedures that must be performed first (checking for diagnostic trouble codes (DTCs), opening doors, rolling down windows, opening hatches, etc.). Always follow the original equipment manufacturer (OEM) instructions.

The technician **SHALL** remove all jewelry, watches, belt buckles or conductive items, as well as anything metallic that can fall out of any pocket and wear appropriate personal protective equipment (PPE).

The vehicle **SHALL** be secured according to the original equipment manufacturer's (OEM) instructions. For example: in park, wheels chocked, parking brake applied, and the vehicle system(s) de-energized/disabled.

The keyless fob, if equipped, **SHALL** be secured outside of key detection range by placing the key fob and/or high-voltage battery disconnects in a secured container.

The technician **SHALL NOT** touch the conductor terminals, or a damaged conductor, until the de-energizing procedure is completed, and the confirmation test proves that high voltage is no longer present in the conductors.

<E3> Safety Steps Prior to Making Contact

To safely de-energize high-voltage circuits, the LEVEL TWO technician **SHALL**:

- Always work on de-energized circuits.
- Ensure that the work environment around the vehicle is safe, clean, dry, and has adequate lighting.
- Remove any jewelry, watches, belt buckles or conductive items, as well as anything metallic that can fall out of any pocket.
- Not work alone.
- Secure the work environment to keep non-trained people away from the area.
- Never leave an electrified propulsion vehicle (xEV) system unattended without the proper signage and barricades.
- Understand the original vehicle manufacturer's (OEM) approved high-voltage system de-energizing procedures for the specific vehicle that is being serviced.
- Inspect all required personal protective equipment (PPE) and tools.
- Wear appropriate personal protective equipment.
- Use a digital multimeter (DMM) rated above the working voltage to at least CAT III 600 V, CAT III 1000 V, or CAT IV 600 V.
- Select test leads and accessories that are CAT-rated to match or exceed the CAT rating of the test tool they are using with at least one insulated alligator clip for the COM connection.

NOTE: One electrical lead equipped with an insulated alligator clip allows the technician to use one hand for the measurement. Connect the lead with the alligator clip to one of the circuit's terminals or ground, then place the other lead in contact with another terminal to make the reading. No more than one hand should be holding a lead or touching vehicle ground at any time.

<E4> Absence of Voltage Verification Process

After all required safety precautions have been carried out, original equipment manufacturer's (OEM) service information may direct the technician to take a voltage reading with an appropriate meter to verify that all sources of high voltage have been isolated or discharged, sometimes referred to as a live-dead-live (LDL) test.

The technician **SHALL** wear appropriate personal protective equipment (PPE) during the "absence of voltage" test.

The technician **SHALL** follow the original equipment manufacturer (OEM) recommended procedure to verify absence of voltage prior to any work being performed.

If service work requires exposure or disconnecting of high-voltage (cables, the technician will need to verify that no voltage is present by taking a reading between high-voltage cable ends as well as between each high-voltage cable end and vehicle ground.

Example – Absence of Voltage Verification Process (LDL test):

1. Identify and find the terminal locations, referenced in the original equipment manufacturer's (OEM) recommended procedures/ service information as the high voltage test locations.
2. Inspect the multimeter and test leads to ensure operational readiness.
3. Rotate the function select switch to the DC measurement function.
4. Wearing the correct personal protective equipment (PPE), measure a known fixed voltage, low voltage 12- or 24-volt battery or a *proving unit* if available, to verify that the meter is reading correctly. A proving unit is a portable, pocket-sized, battery-powered voltage source.
5. Confirm there is no high voltage remaining at the terminal locations, referenced in the manufacturer's recommended procedures/service information as the high voltage test locations. This measurement should read zero volts.
6. As a final step, verify the *operational readiness* using the known fixed voltage source or proving unit to verify the meter is still reading correctly. Only at this point can personal protective equipment be removed.

NOTE: If the vehicle has been de-energized correctly, and if no faults are present in its electrical system:

- No current will be produced by its motor-generators, as they will not be mechanically turning and will have no access to external current sources, except in the case of permanent magnet motors which transfer mechanical energy into electrical energy without an external current source.
- No current will be available at its capacitors, which will have been discharged during the prescribed time interval.
- No current will be present in the vehicle's high-voltage cables, BUT the vehicle's high-voltage battery **WILL** remain charged, and is thus a potential current source, although it will be isolated from the rest of the system.

<E5> High-Voltage Interlock (HVIL)

One or more interlock circuits may be integrated into some of the high-voltage components of many electrified vehicles. An interlock circuit is configured as a series circuit with multiple connectors or switches connected to a low-voltage (5V or 12V) power source.

When all connectors are fully seated, and all switches are closed, there will be current through all components in the interlock circuit. This current results in a specific voltage drop across computer monitoring circuits. If any connector in the interlock circuit is removed, the interlock circuit opens. An open interlock circuit causes a different voltage drop across the computer monitoring circuit.

When an open interlock circuit is detected, the high-voltage contactors in the battery housing are immediately commanded open. An active discharge of the high-voltage bus is also commanded and will complete in less than one second.

If the high-voltage system is successfully de-energized utilizing the procedures in the service information, the interlock circuits will never be needed. The interlock circuits provide an additional layer of high-voltage safety for those not following the procedures outlined in the service information.

<E6> Lockout/Tagout (LOTO)

Lockout/tagout procedures exist to protect technicians from potentially fatal electric shock. The technician should not risk someone re-energizing their work environment.

The technician **SHALL** maintain control of any removed fuses, relays, or manual service disconnect (MSD) in a secured location under lock and key (if possible) to prevent others from reinstalling these items without their knowledge.

The LEVEL TWO person **SHALL** de-energize the high-voltage circuit whenever possible and verify it is de-energized before starting work. If the LEVEL THREE technician must work on a potentially energized circuit, a job hazard analysis **SHALL** be completed, and the appropriate personal protective equipment (PPE) **SHALL** be utilized.

Lockout is used in uncontrolled environments. Tagouts are used in controlled environments with an established group policy for the treatment and use of the tagout[13].

[13] The OSHA (Occupational Safety and Health Administration) standard for *The Control of Hazardous Energy* (Lockout/Tagout) (29 CFR 1910.147) for general industry, outlines specific action and procedures for addressing and controlling hazardous energy during servicing and maintenance of machines and equipment.

<E7> One-Hand Rule

When working with live circuits, only a single hand should be touching a lead, the vehicle, or the ground at any time. This prevents the technician from contacting a circuit and sending electricity through their body if isolation is lost.

<E8> Do Not Work Alone

The LEVEL TWO and/or LEVEL THREE technician(s) **SHALL never** work on a high-voltage vehicle without first notifying someone who is trained in dealing with high-voltage safety procedures.

<E9> Do NOT Back-Probe High-Voltage Connectors

The technician **SHALL NOT** back-probe high-voltage connectors as this will introduce a path for moisture intrusion.

Do not use any sprays, including cleaning sprays, around high-voltage circuits, as this may energize the ionized air surrounding the circuit, making it conductive. Remember that a 400 V DC circuit has a far greater capacity to produce an electrical arc than a 12 V DC circuit. Although the internal AC voltages in some inverters are much higher, the voltage outside the inverter never exceeds high-voltage battery voltage.

Use electrical tape to insulate any exposed high-voltage terminals that have been disconnected.

<E10> Plan and Document the Work

Measurements of potentially live high-voltage, high-current circuits require planning and focus.

- Until an “absence of voltage” test is performed, always assume that the circuit is live, even if the system has been properly de-energized and is free of faults.
- Prepare the environment, brief others, and have an action plan for all contingencies.

Example – Finalize the Work

Any high-voltage connection that is secured with a threaded bolt or nut must be torqued to the original equipment manufacturer (OEM) specification, and not over-torqued. The quality and cleanliness of the electrical connection, as well as its resistance to corrosion, is dependent on proper torque.

Ensure that a part or a tool has not been left in the repaired area.

If the vehicle’s high-voltage system has a removable manual service disconnect (MSD), it must be seated firmly and correctly when re-installed.

The low-voltage battery should not be re-connected until the vehicle’s high-voltage manual service disconnect or switch has been returned to its original position and any removed access covers have been reinstalled.

Once the vehicle has been reassembled and the low-voltage battery connected, the vehicle should be powered on and checked for codes and/or READY status. Some electrified propulsion vehicle (xEV) systems will set codes whenever the system has been disturbed or shut down, so codes may need to be cleared. All electrical systems (such as power windows) that utilize memory need to be initialized and retrained.

SECTION F – TEST INSTRUMENTS AND EQUIPMENT FOR ELECTRIC VEHICLE APPLICATIONS

<F1> Test Tool Inspection

Test instruments and accessories are part of personal protective equipment (PPE)[14]. All equipment **SHALL** be visually inspected before use, and defective or damaged equipment must be repaired and tested before being used again.

[14] Article 110.4 of NFPA 70E (National Fire Protection Association), the Standard for Electrical Safety in the Workplace

The insulation of protective tools, including voltage test indicators, **SHALL** be verified by test and inspection, **SHALL** be rated for circuits and equipment to which they will be connected, and **SHALL** be designed for the environment to which they will be exposed and the way they will be used.

<F2> Inspect Your Test Tools

Test tools **SHALL** be visually inspected frequently to help detect damage and ensure proper operation.

- Check for a broken or damaged case or a faded display. A damaged case may allow an internal arcing condition to reach the user and should not be used.
- Inspect test leads and probes for cut, frayed or broken wires and replace them, as necessary.
- Test leads and probes must have:
    - Shrouded connectors.
    - Finger guards.

- CAT ratings that equal or exceed those of the meter (CAT III 1000 V / CAT IV 600 V).
- Double insulation.

<F3> High Quality Test Leads

The technician should select test leads that are CAT-rated to match or exceed the CAT rating of the test tool they are using.

Use the digital multimeter's (DMM) own continuity testing function to check for internal breaks.

Check test lead resistance procedure:

- Insert leads in the V/Ω and COM inputs.
- Select Ω, touch probe tips securely.
- Good test leads are 0.1 – 0.3 Ω.

<F4> Probes and Probe Accessories

The LEVEL TWO and/or LEVEL THREE person(s) **SHALL** use retractable probes, probe tip covers, or probes with shorter tips to avoid accidentally touching metal to metal and causing a short circuit.

For electrified propulsion vehicle (xEV) applications, the length of exposed test tips **SHALL** be *4 mm (0.16 in.)* to maintain a CAT III and CAT IV environment.

<F5> Test Tool High-Energy Fuse Replacements

The technician **SHALL** replace high-energy fuses with the same quality part and amperage rating per the test tool equipment manufacturer's requirements.

These unique fuses are designed to keep energy generated by an electrical short contained within the fuse enclosure. Ensure that the amperage and voltage ratings of meter fuses meet specifications and that the fuse voltage is equal to or greater than the meter's voltage rating.

NOTE: Never substitute with a non-recommended fuse or bypass the fuse protection in a test tool.

<F6> Types of Equipment and Use Models to Support Safety

Differential Probes

To maintain safety, the electrified propulsion vehicle (xEV) high-voltage system is fully isolated "floating" from the chassis ground. For this reason, multi-channel instruments (oscilloscopes) require isolated channels using separate analog-to-digital (A to D) converters, or differential probes must be used to allow for floating measurements.

<F7> Transients on Electric Vehicles

A high-voltage transient or spike can occur when power is removed to a charged inductor. Transients, also referred to as counter Electromotive Force (EMF), are possible when working with electrified propulsion vehicle (xEV) motors, coils, and capacitors, generating an inductive kick-back pulse like a spark plug firing or a coil being discharged. This spike is narrow, typically under 100 mS, but can reach thousands of volts. A spark can be created between two lines and if the spark is on a high-energy line, all the current in the circuit can feed an arc.

IEC 61010-1:2010 3rd edition (International Electrotechnical Commission) is the present safety standard in use today. In the three-category rating system, the closer an individual is to the power source, the higher the category and the greater the danger. In industrial environments CAT II, III and IV, the available fault current in these high-energy circuits can reach as much as 100,000 amps. In an electrified propulsion vehicle that current may be less but is still extremely dangerous.

A higher voltage rating denotes a higher transient-withstand rating. This means that the meter's input circuitry is designed to withstand voltage transients commonly found in this environment without harming the user. The multimeter must be able to withstand average voltage levels and high voltage spikes and transients that can deliver a shock or produce an arc flash.

It is important to consider both the CAT rating and the voltage rating. For example, a CAT III 1000 V rated meter offers superior protection to a CAT III 600 V rated meter, but a CAT II 1000 V rated meter is not superior to a CAT III 600 V rated meter. That is because in calculating the voltage-withstand ratings, IEC 61010-1 (International Electrotechnical Commission) test procedures consider steady-state voltage, peak impulse transient voltage, and source impedance.

<F8> Test Tool Standards and Ratings

Measurement Category	**Working Voltage (DC or AC rms to ground)**	**Peak Impulse Transient (20 repetitions)**	**Test Source (Ω = V/A)**
CAT III	600 V	6000 V	2 Ohm source
CAT III	1000 V	8000 V	2 Ohm source
CAT IV	600 V	8000 V	2 Ohm source

Measurement Category	**In brief**	**Examples**
CAT IV	Three-phase at utility connection, any outdoor mains conductors	- Refers to the "origin of installation," i.e., where low-voltage connection is made to utility power - Electricity meters, primary overcurrent protection equipment - Outside and service entrance, service drop from pole to building, run between meter and panel - Overhead line to detached building, underground line to well pump
CAT III	Three-phase distribution, including single-phase commercial lighting Minimum Specification for Electrified Propulsion Vehicles (xEVs)	- Equipment in fixed installations, such as switchgear and polyphase motors - Bus and feeder in industrial plants - Feeders and short branch circuits, distribution panel devices - Lighting systems in larger buildings - Appliance outlets with short connections to service entrance

CAT II	Single-phase receptacle connected loads	- Appliance, portable tools, and other household and similar loads
		- Outlet and long branch circuits
		  - Outlets at more than 10 meters (30 feet) from CAT III source
		  - Outlets at more than 20 meters (60 feet) from CAT IV source

Source: Fluke Corporation

The LEVEL TWO and LEVEL THREE technician **SHALL** ensure that the meter and accessories are rated to CAT III 600 V, CAT III 1000 V or CAT IV 600 V, and have the appropriate voltage rating for the electrical environment in which they will be used with a meter rated for the appropriate measurement category (CAT rating) and the voltage level of their application.

<F8.1> Look for Independent Testing and Certification

The technician should ensure that the test instrument they are using is rated for safety and verify their test tools have been tested and certified by two or more independent testing laboratories, such as **UL** (Underwriter Laboratories) in the United States, **CSA** (Canadian Standards Association) in Canada, and **TÜV** (Technischer Überwachungsverein) in Europe.

The marks will be stamped on the meter body and included in the meter's brochures and catalogs. The presence of those marks ensures that the meter has been independently tested and certified to meet those agencies' certification requirements. If in doubt, ask the vendor or manufacturer for proof of compliance with established safety standards.

<F8.2> Ingress Protection (IP) Rating

If the technician works in harsh, wet, or dusty environments, they should use a water- and dust-resistant test instrument. Water and dust resistance standards are defined in IEC 60529 (International Electrotechnical Commission) as levels of ingress protection (IP) from solids and water.

An IP rating has two digits. The first specifies the size of excluded objects. Zero indicates no protection and 6 means that it is dustproof. The second digit specifies the level of protection against water. Zero indicates no protection and 8 means that it is protected against continuous immersion in one meter of water. For example, a rating of "IP67" means the meter is tested to be dustproof and to withstand immersion in water to a depth of one meter for 30 minutes.

NOTE: Safety certification testing for IEC 61010 does not test for compliance with the IEC 60529 IP standard, so check with the manufacturer or vendor for proof of compliance.

<F9> Test Instruments and Specialty Tools

<F9.1> Digital Multimeter

A digital multimeter (DMM) is a test tool used to measure two or more electrical values, principally Electromotive Force (EMF) (volts), current (amps), and resistance (ohms). It is a standard diagnostic tool for electrified propulsion vehicle (xEV) technicians.

The technician should look for a CAT III 600 V, CAT III 1000 V, or CAT IV 600 V rating on the front of meters and testers, and a "double insulated" symbol on the back.

<F9.2> Insulation Tester

In the case of a trouble code entry "insulation resistance too low" or "loss of isolation," the technician may need to disconnect high-voltage components to diagnose the loss of isolation at a component level. Insulation testers provide a quick and easy way to determine the condition of the insulation on wire, generators, and motor windings.

Insulation testers measure very high resistance values by applying a high-voltage signal, 250 V to 1000 V, into the object being tested. They are used after repairs to validate those conductors and components have correct insulation and isolation prior to re-connecting the high-voltage battery to the system.

According to FMVSS 305 S5.4.3.1[15], (Federal Motor Vehicle Safety Standards) insulation resistance must be at least 500 Ω per volt and the measuring voltage of the tester must be at least as high as the operating rated voltage of the component to be tested. The higher the temperature, the lower the insulation resistance. An insulation tester reading of >550 MΩ is expected in most tests. Refer to the original equipment manufacturer (OEM) specifications for specific values.

[15] FMVSS 305 S5.4.3.1 (Federal Motor Vehicle Safety Standards); ***Electrical isolation of AC and DC high-voltage sources.*** The electrical isolation of a high-voltage source, determined in accordance with the procedure specified in S7.6 must be greater than or equal to one of the following:

(a) 500 ohms/volt for an AC high-voltage source
(b) 100 ohms/volt for an AC high-voltage source if it is conductively connected to a DC high-voltage source, but only if the AC high-voltage source meets the requirements for protection against direct contact in S5.4.1.4 and the protection from indirect contact in S5.4.2; or
(c) 100 ohms/volt for a DC high-voltage source.

High-voltage components tested for insulation resistance:

- All high-voltage cables.
- Connections of the high-voltage battery.
- Connections of the high-voltage cables to the safety relay.
- Between shielding and the conductor(s).
- High-voltage coolant heaters.
- Power electronics.
- Battery Management System (BMS).
- Electric motors.
- A/C compressor.

NOTE: Do NOT use PAG oil as it is hygroscopic. Use the original equipment manufacturer (OEM) recommended non-conductive refrigerant oil.

Test Steps for an Insulation Test:

1. Shielding to inner conductor.
2. Inner conductor to chassis ground. (Measuring voltage: 500 V to 1000 V)[16].
3. Shielding to chassis ground.
4. E-Motor windings (Wye or Delta configuration).

[16] Loss of isolation can occur when touching a 12 V power source. It is not always a loss of isolation to the vehicle chassis.

<F10> Insulated Hand Tools

Designed to protect technicians from electrical shock up to 1000 V AC and 1500 V DC, providing two types of protection for electrified propulsion vehicle (xEV) technicians around energized components.

1. Insulated tools help protect individuals against electrical shock and arcing.
2. Insulated tools help protect the equipment being inspected or repaired.

Insulated tools **SHALL** be inspected and deemed safe before beginning work.

LEVEL TWO and LEVEL THREE technicians **MAY** use insulated hand tools when working on or around electrified propulsion vehicle (xEV) sub-components and electrified propulsion vehicle (xEV) batteries.

Refer to Section *<B7> Insulated Hand Tools* in this document for details on insulated hand tools.

According to the ASTM F1505-10 (American Society for Testing and Materials) standard:

- Tools must be completely dielectric up to 1000 V AC. That means no part of the tool's insulation will conduct electricity if it contacts voltage up to that level.
- All parts of the tool, including the insulation, must be flame-resistant (FR) and must function from -4° F (-20° C) to 158° F (70° C).
- Tools such as pliers and cutters should have a guard rail to protect a user's hand from slipping down to the exposed metal part of the tool.

<F11> Proving Unit

Designed as a portable, pocket-sized, battery-powered voltage source that sources a stable AC and DC voltage, the proving unit provides a safe and reliable method to verify that the electrical test measurement tool is operating properly before and after conducting any live tests.

<F12> EV Battery Section Balancing Tool

This tool is used to check state-of-charge and equalize voltage differences between modules when the battery module is replaced. New module(s) need to be levelized (charged or discharged) to have the same state-of-charge (V) as the others in the pack.

Section G – Addendums -- Resources and References

Related and Referenced Regulations and Standards

ASTM International – www.ASTM.org

Standards and technical content development with over 12,000 ASTM (American Society for Testing and Materials) standards operating globally.

Electrical Safety Program Training (Example)

NFPA 70E (National Fire Protection Association) and OSHA 1910, Subpart S 331-335 (Occupational Safety and Health Administration), provides key elements for a "written" electrical safety program and should be referenced as the focus of training programs.

- Training
- Job Safety Planning
- Risk Assessment
- Engineering (Manufacturer Procedures)
- Electrically safe work condition (<50 V)
- Personal protective equipment (PPE) and Tools

Emergency Response Training, Specialized Response Equipment, and Circuit Isolation (Example)

- Electrified propulsion vehicle (xEV) Specialty Tools and Instruments – Use and Understanding
- High-voltage Isolation Safety
- First Responder Practices
- ESS – Energy Storage Systems
  https://www.nfpa.org/~/media/Files/Code%20or%20topic%20fact%20sheets/ESSFactSheet.pdf

- Thermal Runaway
- Stranded Energy
- Toxic and Flammable Gasses Generated
- Deep Seated Fires
- NFPA (National Fire Protection Association) Field Guide Interpretation

FMVSS (Federal Motor Vehicle Safety Standards) **–** https://www.nhtsa.gov/

The Federal Motor Vehicle Safety Standards (FMVSS) are prescriptive U.S. federal regulations specifying design, construction, performance, and durability requirements for motor vehicles. The safety standards establish minimum performance requirements for manufacturers and the equipment used to make a vehicle. The NHTSA administers the Federal Motor Vehicle Safety Standards (FMVSSs), which outline various requirements to ensure vehicles meet the standards of safety that qualify roadworthiness.

- (FMVSS) 141 and 305
  https://www.ecfr.gov/current/title-49/subtitle-B/chapter-V/part-571#571.305

First-Aid Training Including CPR (Example)

- First Aid
  - Identify situations that require first aid response.
  - Assess an environment for safety.
  - Prioritize and apply first aid measures.
  - Evaluate appropriate responses to a person in distress.
  - Communicate effectively with 911 and emergency medical service (EMS) personnel.
  - Summarize the importance of company emergency plans, procedures, and policies.
- CPR – Cardiac Pulmonary Resuscitation.
- AED – Automated External Defibrillator.

IEC (International Electrotechnical Commission)

IEC 61010 are the *electrical requirements for laboratory test and measurement equipment*--microscopes, metrology equipment, FTIRs, Mass Spectrometers, or other devices in a laboratory. 61010 covers the electrical requirements and some of the other hazards for these types of equipment.

Where NFPA 70E (National Fire Protection Association) deals primarily with the personal protection equipment and test environment, IEC 61010 develops international standards for all electrical, electronic, and related technologies providing guidance to test equipment manufacturers regarding how they are designed and manufactured.

NFPA (National Fire Protection Association) – www.NFPA.org

NFPA 70E, "Standard for Electrical Safety in the Workplace" is a standard of the National Fire Protection Association (NFPA). The document covers electrical safety requirements for employees. The NFPA is best known for publishing the National Electrical Code (NFPA 70).

While NFPA 70E training is NOT required by law, except for contractors to the Department of Energy [10CFR 851.23(a)(14)], meeting *OSHA (Occupational Safety and Health Administration)* requirements for electrical safety training is required by law. NFPA 70E helps employers meet the performance requirements of the OSHA standards for electrical safety.

As a *general* guideline relating to personal protective equipment (PPE), the technician may wear arc-rated (AR) Clothing, ***Category 2 PPE***, Minimum Arc Rating of 8 cal/cm^2 (33.5 J/cm^2) or ***Category 4 PPE***, Minimum Arc Rating of 40 cal cm^2 (167.5 J/cm^2), depending on the high-voltage battery chemistry and energy potential. NFPA Standard 70E Table 130.7(C)(15)(c), including arc-rated (AR) clothing, gloves, hard hat, safety glasses or goggles, hearing protection, and leather footwear as required for the voltage being worked on, identifies a complete list of personal protective equipment (PPE) categories and the appropriate arc-rated (AR) clothing for each rating.

NHSTA (National Highway Traffic Safety Administration) **–** https://www.nhtsa.gov/

The *National Highway Traffic Safety Administration* is responsible for keeping people safe on America's roadways through enforcing vehicle performance standards and partnerships with state and local governments. NHTSA reduces deaths, injuries, and economic losses from motor vehicle crashes through education, research, safety standards, and enforcement.

OSHA (Occupational Safety and Health) – OSHA 29 CFR 1910 Subpart S and CFR 1926 Subpart K[17, 18]

With the Occupational Safety and Health Act of 1970, Congress created the Occupational Safety and Health Administration (OSHA) to ensure safe and healthful working conditions for workers by setting and enforcing standards and by providing training, outreach, education, and assistance. OSHA sets enforcement policy and targeted inspection programs and responds to fatalities, catastrophes, and complaints.

[17] OSHA (Occupational Safety and Health Administration) considers all voltages of 50 volts or above, AC or DC hazardous. Electric current, not voltage, passing through the human body causes injury, and the amount of current passing through an object depends on the resistance of the object.

[18] 29 CFR 1910.303(g)(2)(i) generally requires "live parts of electric equipment operating at 50 volts or more" to be "guarded against accidental contact by use of approved cabinets or other forms of approved enclosures" or by other specified means. The guarding requirement does not distinguish between AC and DC voltages. Therefore, the requirement applies to live parts operating at 50 volts or more AC or DC.

- OSHA 1910.132 (Occupational Safety and Health Administration) requires hazard assessment of mechanical, shock, chemical, and electrical explosion (arc flash). Mitigation of hazard can come from design, work practices, or personal protective equipment (PPE).
- Hazards depend on:
  - Vehicle operating voltages.
  - Battery design and chemistry.
  - Electrical bus design and insulation protection.
- Hazards increase due to improper work practices, defective or damaged batteries, or vehicle assembly and damaged vehicles leading to damage of the battery and/or structure.

OSHA General and Specific Duty Clauses

The *general duty* clause requires workplaces to be free from recognized hazards.

Specific duty clauses require employers to comply with OSHA (Occupational Safety and Health Administration) standards.

- General Requirements in 1910.132
- Eye and Face Protection in 1910.133
- Foot Protection in 1910.136
- Electrical Protective Equipment in 1910.137
- Hand Protection in 1910.138
- The Control of Hazardous Energy (Lockout/Tagout) in 1910.147
- Safeguards for Personal Protection in 1910.335
- Electrical Protective Equipment in 1910.335(a)(1)(i)
- Eye and Face Protection in 1910.335(a)(1)(v)

- Insulated Tools in 1910.335(a)(2)(i)
- OSHA 1910.147(a)(1)(i) – This standard covers the servicing and maintenance of machines and equipment in which the unexpected energization or startup of the machines or equipment, or release of stored energy, could harm employees. This standard establishes minimum performance requirements for the control of such hazardous energy.
- 1910.147(a)(3)(i) – This section requires employers to establish a program and utilize procedures for affixing appropriate lockout devices or tagout devices to energy isolating devices, and to otherwise disable machines or equipment to prevent unexpected energization, start up or release of stored energy to prevent injury to employees.
- 1910.147(b) – Definitions applicable to this section.
    - **Energized**. Connected to an energy source or containing residual or stored energy.
    - **Energy isolating device**. A mechanical device that physically prevents the transmission or release of energy, including but not limited to the following: A manually operated electrical circuit breaker; a disconnect switch; a manually operated switch by which the conductors of a circuit can be disconnected from all ungrounded supply conductors, and, in addition, no pole can be operated independently; a line valve; a block; and any similar device used to block or isolate energy. Push buttons, selector switches and other control circuit type devices are not energy isolating devices.
    - **Energy source**. Any source of electrical, mechanical, hydraulic, pneumatic, chemical, thermal, or other energy.
- 1910.147(c)(1) – Energy control program. The employer shall establish a program consisting of energy control procedures, employee training and periodic inspections to ensure that before any employee performs any servicing or maintenance on a machine or equipment where the unexpected energizing, startup or release of stored energy could occur and cause injury, the machine or equipment shall be isolated from the energy source and rendered inoperative.
- 1910.147(c)(2) – Lockout/tagout.
    - 1910.147(c)(2)(i) – If an energy isolating device is not capable of being locked out, the employer's energy control program under paragraph (c)(1) of this section shall utilize a tagout system.
    - 1910.147(c)(2)(ii) – If an energy isolating device is capable of being locked out, the employer's energy control program under paragraph (c)(1) of this section shall utilize lockout, unless the employer can demonstrate that the utilization of a tagout system will provide full employee protection as set forth in paragraph (c)(3) of this section.
- 1910.147(c)(3) – Full employee protection.
    - 1910.147(c)(3)(i) – When a tagout device is used on an energy isolating device which is capable of being locked out, the tagout device shall be attached at the same location that the lockout device would have been attached, and the employer shall demonstrate that the tagout program will provide a level of safety equivalent to that obtained by using a lockout program.
    - 1910.147(c)(3)(ii) – In demonstrating that a level of safety is achieved in the tagout program which is equivalent to the level of safety obtained by using a lockout program, the employer shall demonstrate full compliance with all tagout-related provisions of this standard together with such additional elements as are necessary to provide the equivalent safety available from the use of a lockout device. Additional means to be considered as part of the demonstration of full employee protection shall include the

implementation of additional safety measures such as the removal of an isolating circuit element, blocking of a controlling switch, opening of an extra disconnecting device, or the removal of a valve handle to reduce the likelihood of inadvertent energization.

OSHA Interpretation on Arc Flash Hazards

Arc-flash hazards are also addressed in OSHA 1910.335(a)(1)(v) (Occupational Safety and Health Administration), Safeguards for personnel protection, which requires that personal protective equipment (PPE) for the eyes and face be worn whenever there is danger of injury to the eyes or face from electric arcs or flashes or from flying objects resulting from an electrical explosion. In addition, paragraph (a)(2)(ii) of OSHA 1910.335 requires, in pertinent part, the use of protective shields, barriers, or insulating equipment "to protect each employee from shocks, burns, or other electrically related injuries while that employee is working … where dangerous electric heating or arcing might occur" The OSHA 1910.335(a)(2)(ii) safeguard selected – shield, barrier, or insulating material – must fully protect employees from electric shock, the blast, and arc-flash burn hazards associated with the incident energy exposure for the specific task to be performed. ….. The supplemental measures, which could include the use of arc-rated (AR)/flame-resistant (FR) clothing appropriate to the specific task, must fully protect the employee from all residual hazardous energy (e.g., the resultant thermal effects from the electric arc) …."

https://www.osha.gov/laws-regs/standardinterpretations/1993-09-09-3 and
https://www.osha.gov/laws-regs/standardinterpretations/2006-11-14

SAE International Standards (Society of Automotive Engineers)

- J2344: 2010, "Guidelines for Electric Vehicle Safety"
- J1715-1 and/or J1715-2 standardized terminology
- J2990 – Hybrid and electrified propulsion vehicle (xEV) First and Second Responder Recommended Practice
- J3108 – Electrified propulsion vehicle (xEV) Labels to Assist First and Second Responders, and Others (high voltage safety info.)
- J2344 – Guidelines for Electric Vehicle Safety (EV, HEV, PHEV and FCV high-voltage systems)
- J2950 – Surface Vehicle Recommended Practice
- J1715-1 – Hybrid Electric Vehicle (HEV) And Electric Vehicle (EV) Terminology
- J1715-2 – Battery Terminology
- J1772 – SAE Electric Vehicle And Plug In Hybrid Electric Vehicle Conductive Charge Coupler

Notice and Disclaimers

THE WORD **SHALL**, IN THIS STANDARD, IS USED TO IDENTIFY CONDITIONS THAT **ARE REQUIRED** AND **MUST** BE MET.

THE WORD **MAY**, IN THIS STANDARD, IS USED TO IDENTIFY CONDITIONS THAT **ARE RECOMMENDED** AND **MAY** BE MET.

***ASE Electrified Propulsion Vehicles (xEV) High-Voltage Electrical Safety Standards*, and its recommended practices are developed through a consensus standards development process approved and governed by ASE. This process brings together volunteers representing varied viewpoints and interests to achieve consensus on electrified propulsion vehicle safety issues. These *ASE Electrified Propulsion Vehicles (xEV) High-Voltage Electrical Safety Standards* are developed to serve as a guide, sharing existing industry standards, concepts, and practices followed by individuals working in the automotive, truck, and commercial electrical industry.**

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